COLD-ROLLED AND RECRYSTALLIZATION TEXTURES OF MOLYBDENUM SINGLE CRYSTALS

Chou Pang-Hsin

COLD-ROLLED AND RECRYSTALLIZATION TEXTURES OF MOLYBDENUM SINGLE CRYSTALS*

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The cold-rolled and recrystallization textures of molybdenum single crystals of (110)[001] and (111)[11$\bar{2}$] orientation after a reduction in thickness of 70, 80 and 85 pct were investigated. As the reduction in thickness increased from 70 to 85 pct, the recrystallization textures gradually changed from the (110)[001], (22$\bar{1}$)[114] orientations towards the (320)[001] and (210)[001] orientations. These results can be satisfactorily explained by oriented nucleation.

For the alloys of iron and silicon, there have been quite a few studies /297** (Ref. 1 - 6) concerning the cold-rolled and recrystallization textures of single crystals of (110)[001], (111)[11$\bar{2}$] and (100)[001] orientations. However, little research has been performed for molybdenum single crystals. It has been found that molybdenum single crystals of orientation close to (110) [001] still have the recrystallization texture of (100)[001] after being cold-rolled (Ref. 7). Later, a similar phenomenon was observed with the single crystals of iron-silicon alloys (Ref. 3). No investigation, however, has been made of the cold-rolled and recrystallization textures of molybdenum single crystals of (110)[001] and (111)[11$\bar{2}$] orientations. It is believed that more research on several different body-centered cubic metals and alloys would be helpful in understanding the formation of recrystallization textures in body-centered cubic metals and alloys.

In this study, the cold-rolled and recrystallization textures of molybdenum single crystals of (110)[001] and (111)[11$\bar{2}$] orientation after a reduction in thickness of 70%, 80%, and 85% are investigated. The problem of recrystallization texture formation is discussed from the oriented nucleation point of view.

I. Experimental Method and Process
(Ref. 8)

The transformation recrystallization method/is used to make molybdenum single crystals 1 mm in diameter, 350 mm long and having <110> orientation. The axial direction of the sample deviates only 2° from the <110> direction. The appropriate angle is selected by the Laue X-ray photographic method. Fine sandpaper is used to grind the sample into a slice of single crystal, 0.7 mm thick, and orientation (110)[1$\bar{1}$0] and (111)[1$\bar{1}$0]. The surface layer of transformation is then removed by an electrolytic polishing technique. When single crystals of these two orientations are rolled along the direction
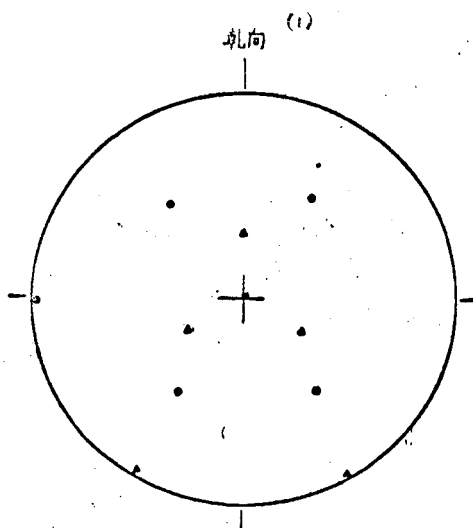

Figure 1

(110) Pole Figure of the Two-Slice
Single Crystals (110)[001] and
(111)[11$\bar{2}$].

⊙ — (110)[001]; ▲ — (111)[11$\bar{2}$]

(1) - Rolling direction

perpendicular to the axial direction
of the original crystal, the orienta-
tions become (110)[001] and (111)[11$\bar{2}$].
Their (110) pole figure is shown in
Figure 1.

The samples are rolled with two,
roller type rolling machines with a
roller diameter of 70 mm. To reach
the 70 - 85% reduction in thickness,
cold-rolling is required approximately
20 - 40 times. The cold-rolled sam-
ples are then annealed inside a high
temperature vacuum furnace. These   /299
cold-rolled or annealed samples are
then treated by the method of electro-
lytic polishing and electrolytic
etching, and the micro-structure is
observed. A series of pictures are
taken at different angles by the X-ray
photography method (light source is
CuK$_\alpha$). The polar diagrams are then
drawn, and the textures are determined.

## II Experimental Results

1. Cold-rolled Textures

Figures 2 a, b, and c represent (110) polar diagrams of a single crystal of
orientation (110)[001], after a reduction in thickness of 70%, 80% and 85%.
Figures 3 a, b, and c represent the (110) polar diagrams of a single crystal of
orientation (111)[11$\bar{2}$], after reduction in thickness of 70%, 80% and 85%. The
single crystal of orientation (110)[001], after a reduction in thickness of
70 - 85%, has a pair of symmetric textures (111)[11$\bar{2}$] and (111)[$\bar{1}\bar{1}$2], and the
original orientation of (110)[001] is still preserved. As the degree of de-
formation increased, the {111}<112> texture became strengthened, and the
{110}<001> texture was weakened. After the 85% reduction in thickness, a pair
of new, relatively weak textures (210)[001] appeared. Figure 4a shows a pic-
ture of the microscopic structure of a single crystal of orientation (110)[001],
after 70% reduction in thickness. It can be seen that, after the single crys-
tal has been rolled and deformed, there is a deformation band structure, but
no deformation twin crystals appear. The single crystal of orientation (111)
[11$\bar{2}$], after reduction in thickness of 70 - 85%, still retains the (111)[11$\bar{2}$]
orientation, and at the same time acquires a pair of relatively weak textures
(110)[001]. As the degree of deformation increases, textures become more and
more dispersed. After 85% reduction in thickness, a new pair of relatively
weak textures (210)[001] is obtained. The structure of a single crystal of
orientation (111)[11$\bar{2}$] after the deformation is similar to that of the (110)
[001] single crystal, except that the deformation band appears to be finer and

轧向 (1)

a

轧向 (1)

b

轧向 (1)

c

Figure 2

(110) Pole Figures of (110)[001] Single Crystal After Reduction in Thickness of 70% (a), 80% (b) and 85% (c).

o — (110)[001]; Δ — (111)[11$\bar{2}$];
∇ — (111)[$\bar{1}\bar{1}$2]; ⊙ — (210)[001]

(1) - Rolling direction
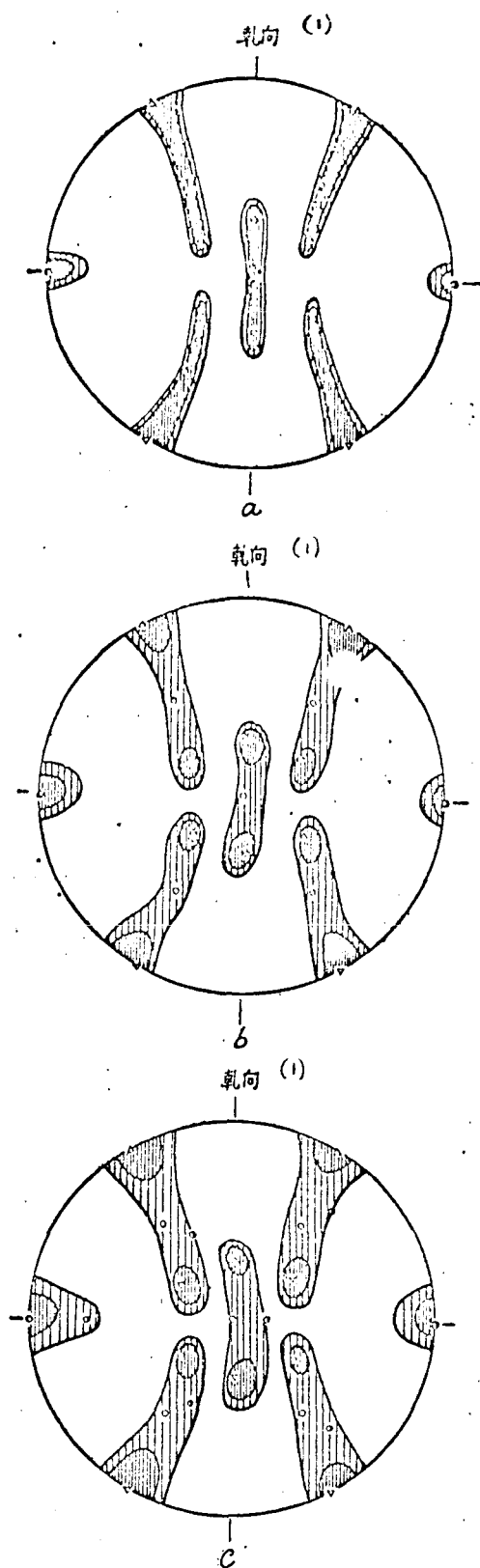
denser.

2. Recrystallization Textures

When the single crystals of orientations (110)[001] and (111)[11$\bar{2}$] are examined by the X-ray photography technique, after being cold rolled 70 - 85%, and annealed at 1300°C for 15 minutes, no new crystal grain of recrystallization is observed. The recrystallization temperature is higher than the general polycrystalline molybdenum sample. Figure 4b shows a sample taken from the heating process with annealing at 1500°C, after the (110)[001] single crystal has been cold-rolled 70%. It can be seen that the new crystal grains readily first appear at the boundaries of the deformation band; the number of grain nuclei is relatively small. Crystal grains are larger in size after the completion of recrystallization. Samples after being cold-rolled 80%, annealed and recrystallized, have an average crystal grain diameter of about 0.12 mm. During the recrystallization process, the {111}<112> texture is relatively stable, and disappears gradually in the later period of the recrystallization process. For all the samples, the complete recrystallization structure is obtained after annealing at 1500°C for 30 minutes. Figures 5 a, b and c show the (110) pole figures of a (110)[001] single crystal after being cold-rolled 70%, 80%,
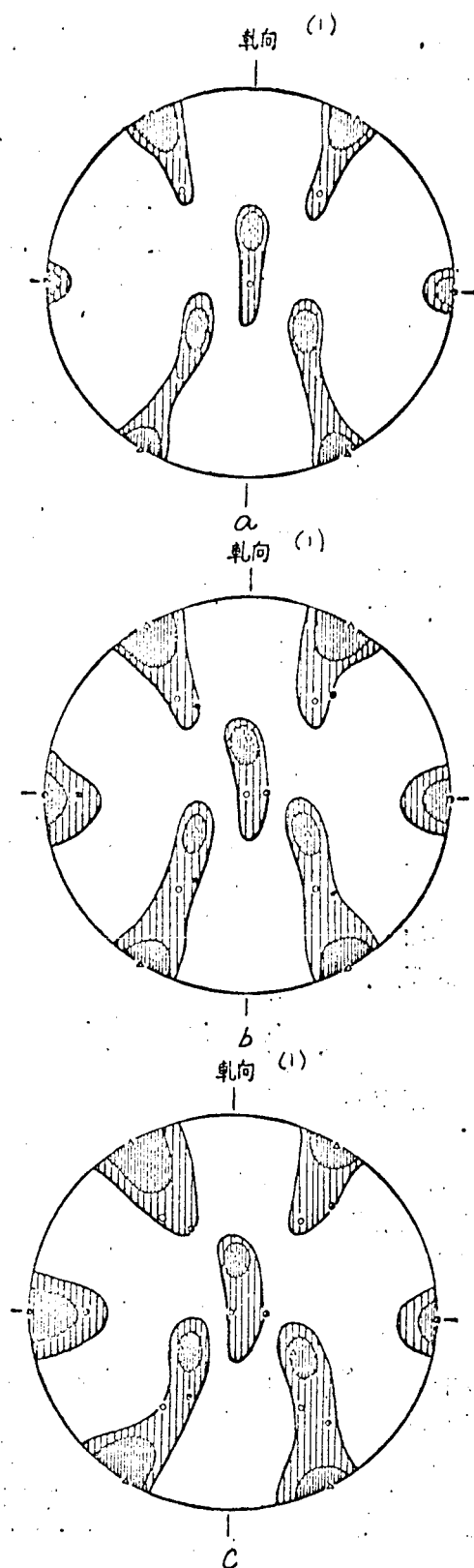
3

Figure 3

(110) Pole Figures of (111)[11$\bar{2}$] Single Crystal After Reduction in Thickness of 70% (a), 80% (b), and 85% (c).

o — (110)[001]; Δ — (111)[11$\bar{2}$]; ⊗ — (320)[001]; ⊙ — (210)[001]

(1) - Rolling direction

and 85%, annealed, and recrystallized. Figures 6 a, b and c show the (110) pole figures of a (111)[11$\bar{2}$] single crystal after being cold-rolled 70%, 80% and 85%, annealed, and recrystallized. The (110) [001] single crystal, after being cold-rolled 70% and annealed, developed (110) [001] and weaker (221)[11$\bar{4}$], (22$\bar{1}$)[114] recrystallization textures. There is a common [1$\bar{1}$0] direction among them which is perpendicular to the rolling direction. The sample rolled 80% and annealed has a concentrated (110)[001] recrystallization texture. The sample cold-rolled 85% and annealed, developed (110)[001] and weaker /301 (120)[001], (210)[001] recrystallization textures. Among them, there is a common [001] direction which is parallel to the rolling direction. After being cold-rolled 70% and annealed, the single crystal of orientation (111)[11$\bar{2}$] acquired (110) [001] and weaker (22$\bar{1}$)[114] recrystallization textures. Among them there is a common [1$\bar{1}$0] direction which is perpendicular to the rolling direction. The sample, which was cold-rolled 80% and annealed, developed (110)[001] and (320)[001] recrystallization textures. The sample cold-rolled 85% and annealed had (110)[001] recrystallization textures. Among them, there is a common direction [001] which is parallel to the rolling direction.
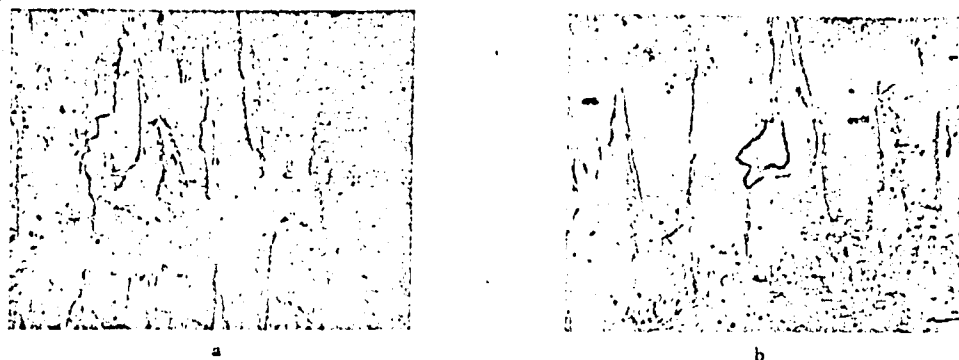
<div align="center">a   b</div>

<div align="center">Figure 4</div>

The Microscopic Structural Pictures of a (110)[001]
Single Crystal After 70% Cold-Rolling (a), and During
the Annealing Process (b). × 150 (↑ Rolling direction).

III. Discussion of Results

From the above results, it may be concluded that -- although the cold-
rolled and recrystallization textures of (110)[001] and (111)[11$\bar{2}$] molybdenum
single crystals are similar to those of the single crystals of iron-silicon
alloy with the same orientations -- there are also dissimilarities. The (110)
[001] molybdenum single crystal does not develop twin components when deformed
under cold-rolling, and therefore does not form a (100)[011] texture. No
{221}<114> recrystallization texture was observed when the iron-silicon single
crystal was cold-rolled 70% and annealed. Comparing the cold-rolled textures
at different degrees of reduction and the recrystallization textures of molyb-
denum single crystals of orientations (110)[001] and (111)[11$\bar{2}$], we found,that
after cold-rolling,a texture having the same orientation as the recrystalliza-
tion texture actually exists. During annealing and recrystallization, this
texture probably passes through a recrystallization process, becomes the
nucleus for recrystallization, and then develops into a recrystallization tex-
ture. However, why do the recrystallization textures of single crystals of
these two orientations vary gradually from (22$\bar{1}$)[114], (110)[001] towards
(320)[001], (210)[001], with an increase in the degree of deformation? This
question requires further explanation.

At present, there is still a dispute concerning the main factor leading
to the formation of recrystallization textures. To summarize, there are two
different opinions. One opinion holds that the orientation of the recrystalli-
zation nucleus lies in a narrow range and -- when the orientation of the crys-
tal nucleus is different from that of the main deformation texture and that
of its twin component -- the crystal nucleus can grow and develop into the
recrystallization texture. This is called the "oriented nucleation" theory.
The other opinion assumes that the orientation of the recrystallization nuclei
is random and that the formation of the recrystallization texture is mainly
due to the result of selective growth between the orientation of recrystalliza-
tion nuclei and that of the deformation texture of the original crystal. This

<div align="right">5</div>
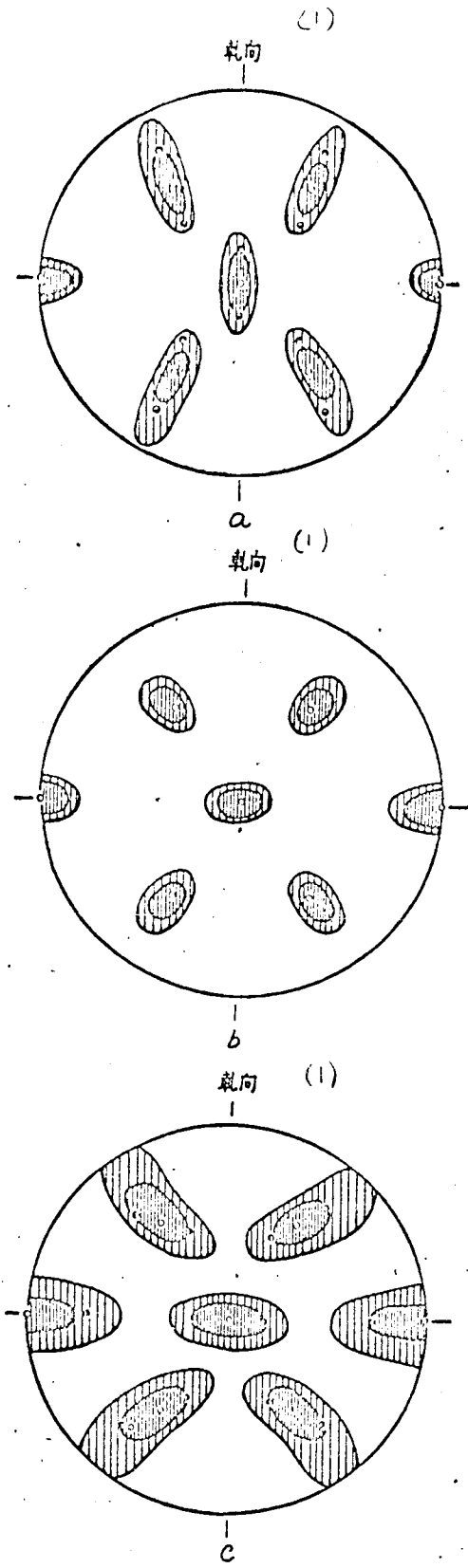
Figure 5

(110) Pole Figure of the Cold-
Rolled and Annealed (110)[001]
Single Crystal. (a) 70% rolled,
(b) 80% rolled, (c) 85% rolled.
The annealing temperature is
1500°C.

⊝ — (221)[11$\bar{4}$]; ⊙ — (22$\bar{1}$)[114];
○ — (110)[001]; ◐ — (120)[001];
◑ — (210)[001].

(1) - Rolling direction

is called the "oriented growth" hypothe-
sis.

Hsun Hu (Ref. 4) has explained the
formation of (110)[001] and (210)[001] re-
crystallization textures of a (110)[001]
iron-silicon single crystal after cold-
rolling and annealing. It was assumed
that the deformation texture of orienta-
tion {111}<112> can lead to the growth
of the recrystallization nuclei of {110}
<001> orientation and forms the {110}<001>
recrystallization texture. The deforma-
tion texture {110}<001> can also lead to
the growth of the recrystallization nuclei
of {120}<001> orientation, and therefore
a {120}<001> recrystallization texture
can also be obtained. However, from the
point of view of oriented growth, it is
very difficult to explain the above ex-
perimental results for the molybdenum
single crystals. As the degree of de-
formation increases, why do the recrystal-
lization textures change from (22$\bar{1}$)[114],
(110)[001] to (320)[001] and (210)[001],
even though the main deformation texture
is {111}<112>? According to the oriented
growth theory, the (120)[001] recrystalli-
zation texture must be obtained more
readily in (110)[001] single crystal speci-
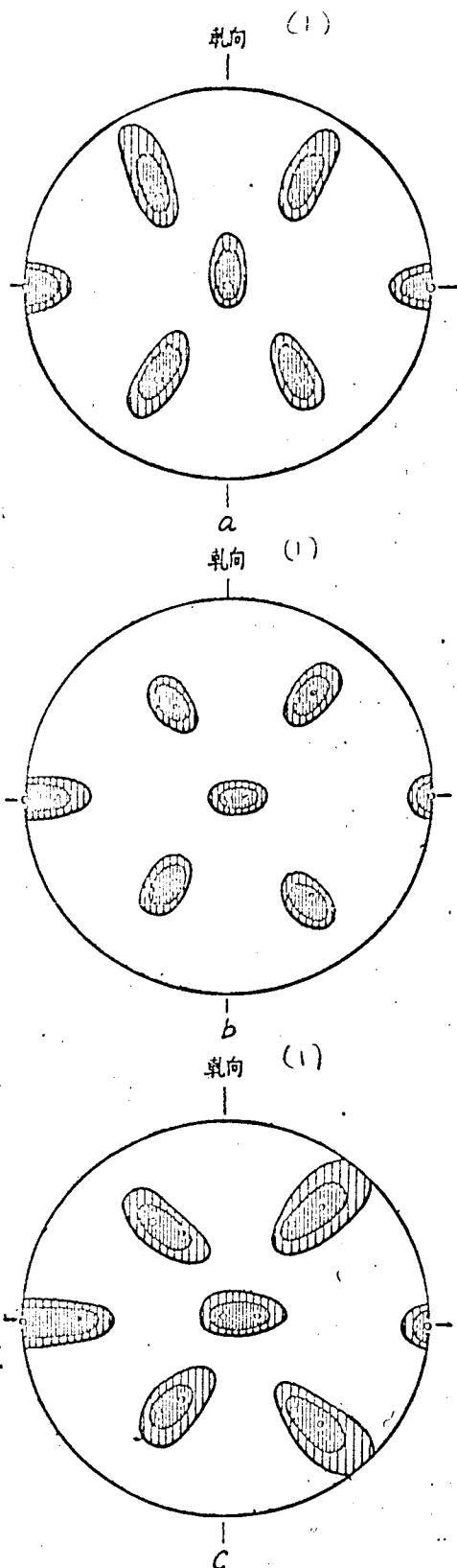mens cold-rolled 70% than in specimens

6

轧向 (1)

a

轧向 (1)

b

轧向 (1)

c

(110) Pole Figure of the Cold-
Rolled and Annealed (at 1500°C)
(111)[11$\bar{2}$] Single Crystal.
(a) 70% rolled, (b) 80% rolled,
(c) 85% rolled.

⊕ — (22$\bar{1}$)[114];   ○ — (110)[001];
⊗ — (320)[001];   ◐ — (210)[001]

(1) - Rolling direction

cold-rolled 85%. This is due to the fact
that the (110)[001] deformation texture is
stronger in a 70% cold-rolled specimen
than in a 85% cold-rolled specimen. This
is not the case, however. Walter and
Hibbard (Ref. 3) investigated silicon-iron
single crystals of these orientations, and
assumed that those components of deforma-
tion textures which have the same orienta-
tion as the recrystallization texture might
become the nuclei in recrystallization.
Dunn and Koh (Ref. 1, 2) proposed adopting
the oriented nucleation theory to explain
the formation of the recrystallization
textures (110)[001], (320)[001] and (210)
[001], after the silicon-iron single crys-
tals are cold-rolled and annealed. However,
an explanation is only provided for the
source of the crystal nuclei of (110)[001]
orientation, and not for the sources of
crystal nuclei of orientations (320)[001]
and (210)[001].

In order to explain the possible
source of recrystallization nuclei and the
rule according to which the orientation
changes with a change in the degree of de-
formation, first let us discuss the trans-
formation of the slip systems when a crys-
tal of (111)[11$\bar{2}$] orientation is deformed
by rolling. Figure 7 shows a standard
pole figure of a (111)[11$\bar{2}$] orientation
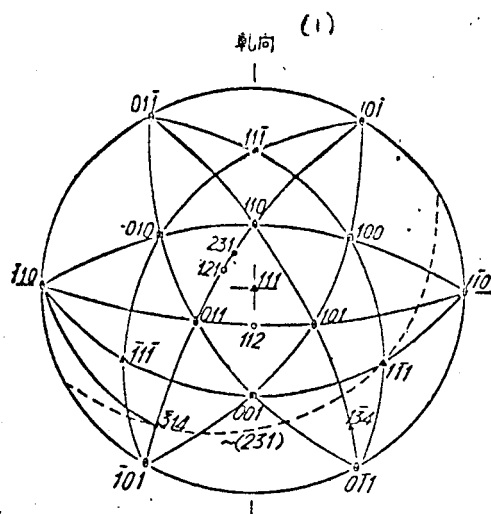single crystal. From the figure, it may   /302

Figure 7

The Standard Pole Figure of a Crystal With Orientation (111)[11$\bar{2}$].

(1) — Rolling direction

be readily seen that in rolling deformation the six sets (0$\bar{1}$1)[111], (10$\bar{1}$)[111], (1$\bar{1}$0)[111], (01$\bar{1}$)[$\bar{1}$1$\bar{1}$], (10$\bar{1}$)[1$\bar{1}$1] and (1$\bar{1}$0)[11$\bar{1}$] of slip systems do not easily slip, while for (011)[11$\bar{1}$], (101)[11$\bar{1}$], (110)[1$\bar{1}$1], (110)[$\bar{1}$1$\bar{1}$], (011)[1$\bar{1}$1] and (101)[$\bar{1}$1$\bar{1}$], slip may occur. Considering the differences in the angle between the flow direction of the metal and the slip direction of each set of slip systems, we know that only the tangential stress component cos $\times$·cos λ·F is not sufficient to determine whether slip will occur at a particular set of slip systems when the crystal is rolled. ($\times$ is the angle between the rolling direction and the normal line of the slip plane; λ is the angle between the rolling direction and the slip direction; F is the stress upon the specimen.) It is necessary to introduce the effective tangential stress component cos $\times$·cos λ· ·cos ψ·F, where ψ is the angle between the slip direction and the metal flow direction. In rolling deformation, ψ is the angle between the slip direction and the metal flow direction. In rolling deformation, ψ is equal to λ. The values of cos $\times$·cos λ and cos $\times$·cos λ·cos ψ for the six sets of slip systems are listed in Table 1. From the value of cos $\times$·cos λ·cos ψ, it can be seen that in the rolling deformation, slip occurs most readily with systems (011)[11$\bar{1}$] and (101)[11$\bar{1}$]. The systems (110)[1$\bar{1}$1] and (110)[$\bar{1}$1$\bar{1}$] are next, followed by systems (011)[1$\bar{1}$1] and (101)[$\bar{1}$1$\bar{1}$]. When we were studying the plastic deformation of molybdenum single crystals (Ref. 8), it was found that slip often occurs concurrently on two sets of {110} surfaces along the same <111> direction. Since the tangential stress components are different on these {110} surfaces, the apparent slip surface composed after the combined slip may be {112}, {123}, {145}...{110}. When a (111)[11$\bar{2}$] single crystal is deformed by rolling, the slip occurs most easily at systems (011)[11$\bar{1}$] and (101)[11$\bar{1}$]. Since the effective tangential stress components of these two systems are equal, the apparent slip surface formed after the combined slip is probably (112) (see Figure 7). After the slip, the rotating axis for the bending of the lattice is [$\bar{1}$10]. In order that the two sets of slip systems (011)[11$\bar{1}$] and (101)[11$\bar{1}$] may still be active after the rotation of the crystal, the crystal orientation, after rolling, will rotate clockwise around [$\bar{1}$10], the slip direction will be far from the rolling direction, and thus the deformation textures (22$\bar{1}$)[114] and (110)[001] are obtained. As the reduction increases, the slip of systems (110)[1$\bar{1}$1] and (011)[1$\bar{1}$1] becomes more and more important. Since the effective tangential stress components of these two systems are not equal, the apparent slip surface formed after the combined slip cannot be (121). If slip on the surface (011) and (110) is distributed according to the effective tangential

TABLE 1

VALUES OF cos ×·cos λ AND cos ×·cos λ·cos ψ AT DIFFERENT SLIP SYSTEMS WHEN A (111)[11$\bar{2}$] SINGLE CRYSTAL IS ROLLED

Slip System	Angle × Between the Rolling Direction and the Normal Line of the Slip Surface	Angle λ Between the Rolling Direction and the Slip Direction	Angle ψ Between the Metal Flow Direction and the Slip Direction.	cos ×· cos λ	cos ×· cos λ· · cos ψ
(011)[11$\bar{1}$] (101)[11$\bar{1}$]	73°13'	19°28'	19°28'	0.273	0.257
(110)[1$\bar{1}\bar{1}$] (110)[$\bar{1}$1$\bar{1}$]	54°44'	61°52'	61°52'	0.273	0.157
(011)[1$\bar{1}\bar{1}$] (101)[$\bar{1}$1$\bar{1}$]	73°13'	61°52'	61°52'	0.137	0.0965

stress component, then the apparent slip surface formed after the combined slip is probably close to (231) (see Figure 7). After the action of these two slip systems, the rotating axis of the lattice bending is, on the average, [$\bar{3}$14]. In order that the two sets of slip systems (110)[1$\bar{1}$1] and (011)[1$\bar{1}$1] be still effective after the crystal rotation, the orientation of a crystal after /303 rolling will rotate clockwise around [$\bar{3}$14], and the slip direction [1$\bar{1}$1] will approach the rolling direction. Due to the above effects of the four sets of slip systems (011)[11$\bar{1}$], (101)[11$\bar{1}$], (110)[1$\bar{1}$1] and (011)[1$\bar{1}$1], the lattice orientation is rotated. On the average, the positions of the rotating axis fall on the line connecting [$\bar{1}$10] and [$\bar{3}$14] (see Figure 7), and the rotation can only be clockwise. As the degree of deformation increases, the effect of the slip systems (110)[1$\bar{1}$1] and (011)[1$\bar{1}$1] increases, the position of the average rotation axis gradually moves from [$\bar{1}$10] toward [$\bar{3}$14], and the angle of rotation of the lattice orientation also increases. A similar procedure can be followed in discussing the lattice orientation variation when the slip systems (011)[11$\bar{1}$], (101[11$\bar{1}$], (110)[$\bar{1}$1$\bar{1}$] and (101)[$\bar{1}$1$\bar{1}$] are active. In this case, the positions of the rotation axis fall on the line connecting [1$\bar{1}$0] and [1$\bar{3}$4], and the rotation is counter-clockwise. The geometric relations between the (111)[11$\bar{2}$] orientation and (22$\bar{1}$)[114], (110)[001], (320)[001], (210)[001], (310)[001], (410)[001] and (100)[001] are analyzed and listed in Table 2 and Figure 8. From Table 2 and Figure 8, it can be seen that a geometric relationship exists between the (111)[11$\bar{2}$] orientation and orientations such as (110)[001], and that the angle rotated about a certain axis is constant. The positions of these axes fall exactly on the line connecting [$\bar{1}$10] and [$\bar{3}$14]. As the orientation varies from (110)[001] toward (100)[001], the positions of the rotating axes also move from [$\bar{1}$10] toward [$\bar{3}$14], and the angle of rotation becomes larger. This and the analysis given above agree with the fact that the deformation texture (210)[001] appears only after relatively large deformations.

TABLE 2

THE GEOMETRIC RELATIONSHIP BETWEEN THE (111)[11$\bar{2}$]
ORIENTATION AND (110)[001], ETC.

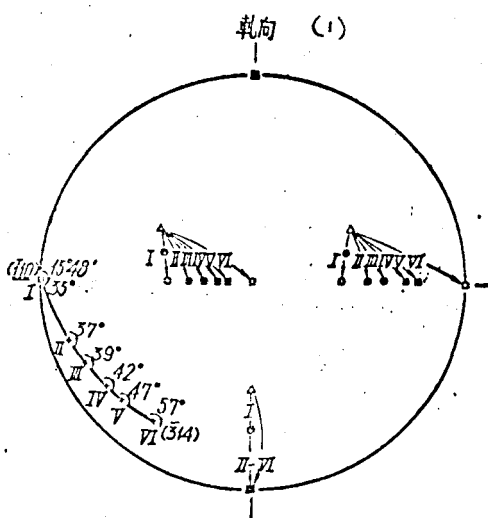| Orientation Obtained After Rotation of the (111)[11$\bar{2}$] Orientation	Position of Rotating Axis (see Figures 7, 8)	Angle of Rotation
(22$\bar{1}$)[114]	I [$\bar{1}$10]	15°48'
(110)[001]	I	35°
(320)[001]	II	37°
(210)[001]	III	39°
(310)[001]	IV	42°
(410)[001]	V	47°
(100)[001]	VI [$\bar{3}$14]	57°

轧向 (1)

Figure 8

The Geometric Relationship Between the (111)[11$\bar{2}$] Orientation and (22$\bar{1}$)[114], (110)[001], (320)[001], (210)[001], (310)[001], (410)[001], and (100)[001] Orientations [(100) Pole Figure].

△——(111)[11$\bar{2}$]; ⊖——(22$\bar{1}$)[114];
○——(110)[001]; ⊗——(320)[001];
◑——(210)[001]; ⊠——(310)[001];
◨——(410)[001]; □——(100)[001].

(1) - Rolling direction

Although the (111)[11$\bar{2}$] orientation is a stable orientation with respect to rolling deformation, when a (111)[11$\bar{2}$] crystal is rolled, part of the lattice orientation can still be rotated, due to the interaction among many sets of the slip systems, and forms weak deformation textures such as (22$\bar{1}$)[114], (110)[001], (320)[001], (210)[001]. At recrystallization, these deformation textures may become the recrystallization nuclei, by way of the isotropic recrystallization process, and develop into recrystallization textures, such as (22$\bar{1}$)[114], (110)[001], (320)[001] and (210)[001]. When a (111)[11$\bar{2}$] single crystal is rolled, slip first takes place at slip systems (011)[11$\bar{1}$] and (101)[11$\bar{1}$] and then at systems (110)[1$\bar{1}$1] and (011)[1$\bar{1}$1]. Therefore, the rotating axis of part of the lattice orientation is not necessarily limited to position [$\bar{3}$14]. After the cold-rolling, it is not possible to obtain the deformation texture (100)[001], nor the (100)[001] recrystallization texture. However, it is possible to obtain the recrystallization texture (310)[001]. When studying the cold-rolled and recrystallization textures of a (110)[001] iron-silicon single crystal (Ref. 7), we obtained

concentrated (310)[001] and (410)[001] recrystallization textures.

The situation when a (110)[001] single crystal is rolled is similar to that when a (111)[11$\bar{2}$] single crystal is rolled. Because the slip systems when a (110)[001] single crystal is rolled are (011)[11$\bar{1}$], (101)[11$\bar{1}$], (01$\bar{1}$) [111] and (10$\bar{1}$)[111] (Ref. 6), due to the effect of these four sets of slip systems, the orientation of a (110)[001] single crystal will rotate around [$\bar{1}$10] during the rolling process and form a stable deformation texture {111} <112>. When deformation is continued, starting from deformation texture {111}<112>, it is possible to obtain deformation textures (320)[001], (210) [001] and recrystallization textures (320)[001], (210)[001] after annealing. This explains the fact that recrystallization textures (110)[001] and (320)[001] are obtained when a (111)[11$\bar{2}$] single crystal is cold-rolled 80% and annealed, while only recrystallization texture (110)[001] -- and not (320)[001] -- is obtained when a (110)[001] single crystal is cold-rolled 80% and annealed.

When a (111)[11$\bar{2}$] single crystal is cold-rolled 80 - 85% and annealed, only recrystallization textures (320)[001] and (210)[001] are obtained, but not recrystallization textures (230)[001] or (120)[001]. The reason for this probably lies in the fact that there is a slight deviation between the rolling direction and [11$\bar{2}$] direction, which causes slip systems (110)[1$\bar{1}$1], (011) [1$\bar{1}$1] to slip more readily than slip system (110)[1$\bar{1}\bar{1}$], (101)[$\bar{1}$1$\bar{1}$]. Thus, after the deformation of a crystal, only deformation textures (320)[001] and (210)[001] are formed. A pair of symmetric deformation textures (111)[11$\bar{2}$] and (111)[$\bar{1}\bar{1}$2] are obtained when a (110)[001] single crystal is cold-rolled. Therefore, after being rolled 85%, a pair of symmetric deformation textures (120)[001] and (210)[001] may be obtained [(120)[001] is probably weaker than (210)[001]; therefore, only (210)[001] can be observed on the pole figure] and only after annealing is a pair of recrystallization textures (120)[001] and (210)[001] obtained.

Summarizing the above discussion, we believe that for single crystals having this type of orientation, after being cold-rolled 70-85%, oriented nucleation is the principal factor leading to the development of recrystalliza- tion textures. When crystals are rolled, due to the interaction of many sets of slip systems, deformation textures of a certain orientation are formed. This deformation texture becomes the recrystallization nucleus, probably by means of isotropic recrystallization. The fact that interaction among the sets of slip systems induces the rotation of part of the lattice orientation when the single crystal (111)[11$\bar{2}$] is rolled explains the following phenomena. For the single crystal of this type of orientation, the recrystallization tex- tures change from (22$\bar{1}$)[114], (110)[001] toward (320)[001], (210)[001].

IV. Conclusions

1. When a (110)[001] molybdenum single crystal is cold-rolled 70-85%, the deformation textures are mainly (111)[11$\bar{2}$] and (111)[$\bar{1}\bar{1}$2], in addition to the weak one (110)[001]. After being cold-rolled 85%, a weak deformation texture (210)[001] is formed.

2. When a (110)[001] molybdenum single crystal is cold-rolled 70% and

annealed, the recrystallization textures are (110)[001] and weaker (211)[11$\bar{4}$] and (22$\bar{1}$)[114]; after 80% reduction and annealing, the recrystallization texture is (110)[001]; after 85% reduction and annealing, the recrystallization textures are (110)[001] and weaker (120)[001], (210)[001].

3. When a (111)[11$\bar{2}$] molybdenum crystal is cold-rolled 70-85%, the deformation texture is mainly (111)[11$\bar{2}$] aside from the weaker one (110)[001]. After 85% reduction, weak deformation texture (210)[001] is formed.

4. When a (111)[11$\bar{2}$] molybdenum single crystal is cold-rolled 70% and annealed, the recyrstallization texture is (110)[001] and weaker (22$\bar{1}$)[114]; after 80% reduction and annealing, the recrystallization textures are (110)[001] and (320)[001]; after 85% reduction and annealing, the recrystallization textures are (110)[001] and (210)[001].

5. Among the cold-rolled specimens, deformation textures with the same orientation as recrystallization textures already exist. These deformation textures may become nuclei of the recrystallization by means of isotropic recrystallization.

6. Analyzing the interaction of the slip systems when a (111)[11$\bar{2}$] orientation single crystal is rolled, we may most satisfactorily explain the fact that the recrystallization texture changes gradually from (110)[001] to (210)[001] as the reduction is increased for a single crystal of this orientation from the oriented nucleation point of view. /305

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